NREL
NATIONAL RENEWABLE ENERGY LABORATORY

System Advisor Model: Enhanced Shading Analysis Roadmap 2013-2015

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Background

The System Advisor Model (SAM) is a broad and robust set of models and frameworks for analyzing both system performance and system financing. It does this across a range of technologies dominated by solar technologies including photovoltaics (PV) and concentrated solar power (CSP).

The U.S. Department of Energy (DOE) Solar Energy Technology Program requested the SAM development team to review the photovoltaic performance modeling with the development community and specifically, with the independent engineering community. In April 2013, the systems modeling team at NREL hosted an onsite technical review committee (TRC) to invite discussion and guidance from the industry on how to best prioritize research and development in PV systems modeling with a focus on improving the System Advisor Model (SAM) tool. The full day meeting revealed general agreement regarding several key areas for improvement to the tool. A consensus emerged that enhanced 3D scene shading analysis capabilities were critically important for SAM to be more broadly accepted. [1]

Timeline

To implement TRC feedback with regards to 3D shading, the SAM development team proposed a plan of action to DOE that was accepted and is outlined below:

1. June-August 2013: investigate various options for integrating or interfacing with 3D scene shading software tools, balancing various tradeoffs: development time, complexity, cost, ease of use to end user, integration with SAM, compatibility with any standard data formats, ability for the SAM team to modify and improve a tool over time, and other factors, including potential competitive concerns with other tools.
2. September 2013: provide a 5-10 page report (this document) to DOE with a recommendation on the best path forward
3. August 2014: release a new version of SAM that implements the development plan for enhanced shading analysis in accordance with DOE guidance and funding

Project Overview

Several approaches are possible for creating a 3D scene representing PV system installation and calculation of the shade impact. One approach could be to partner with commercial software vendors that have similar tools and investigate what levels of integration might be possible with SAM. Another option would be to implement such a capability from scratch with SAM using standard, well documented methodologies for 3D shade calculations. This is the approach taken by the two most common and similar European PV modeling software: PVsyst and PV*SOL.

Either approach represents a significant development activity each with its own benefits and shortcomings. These tradeoffs are analyzed subsequently.

Consultations and Options

We first surveyed other groups within NREL that have significant experience with similar 3D modeling activities. Naturally, both the residential and commercial buildings modeling and simulation groups have software for generating 3D models of a building. In addition, we had direct conversations with numerous industry participants, and performed a survey of similar capabilities in other tools. The discussions and surveys are expanded upon below.

1. We spoke with Scott Horowitz, the lead developer for the BeOpt residential buildings optimization model. In BeOpt, OpenGL 3D software technology is used to render a representation of the building under consideration, but all of the editing and user interaction occurs in 2D space. No shading calculations are performed within BeOpt, as OpenGL is a rendering pipeline that to our knowledge does not return the coordinates of objects after they have been transformed to a 3D perspective and rendered. This data is necessary for determining shade impacts at a particular sun position.
2. We spoke with Nick Long, a senior technical lead for the EnergyPlus software. EnergyPlus does have shading calculations written in FORTRAN, and is tied closely to the 3D representation in the OpenStudio tool. The SAM code is entirely in C++, so there is no opportunity to directly leverage the EnergyPlus tool if the goal were to integrate a shading tool within SAM. Nick indicated that in fact the basic 3D calculations are not very difficult to implement, and suggested that for our purposes, it would be best to implement our own analysis tool from scratch.

3. We had two phone calls with Juan Pons, the developer of the Skelion tool. Skelion is a Trimble Sketchup (formerly Google Sketchup) plugin that performs a shading analysis on a building model with PV panels and interacts with PVWatts^{TM} over the web to estimate the reduced system performance. Skelion also has a PVsyst output option. We talked to Mr. Pons about having a SAM output option as well, and explained the various ways in which his tool could integrate with SAM, specifically the SAM Simulation Core (SSC) software development kit (SDK). We have not heard back from the Skelion team since mid-June, and are unsure about their future plans.
4. Concept3D is a DOE SunShot Funding Opportunity Announcement (FOA) awardee that is developing a unique end-to-end building energy audit assessment tool that incorporates PV modeling called Simuwatt. It includes a very detailed 3D building geometry model, enhanced rendering with shading and lighting, energy simulation of the building, and calculation of a shading factor matrix that is fed into the SAM engine via a web service. Simuwatt is an iPad-based tool that relies on numerous NREL and 3rd party web services for PV and LCOE simulation via SAM, utility rate data, incentive data, building simulation, and additional energy audit specific data, forms, and processes to develop streamlined workflows. Based on our understanding of the Simuwatt tool, we do not see an integration path with the SAM desktop tool beyond "standardization" of shading data formats. Simuwatt is already using SAM in the backend, so we expect that the tool would be able to export the shading factor matrix to be used in the SAM desktop tool as well. Simuwatt is under development and has not been publicly released at this time.
5. During the SAM virtual conference, Ryan Welch, from Kieran Timberlake Architects, presented work on using a commercial tool called Rhinoceros3D (Rhino3D) to model a 3D scene and calculate shading losses, including the diffuse view factor reductions. He showed how it is possible to use a complex 3D modeling tool and generate appropriate shading factor data that can be pulled into SAM directly. We see this as an opportunity to move towards "standardization" of shading data inputs for PV modeling tools, rather than a way to integrate a 3D capability into SAM. Mr. Welch's presentation and audio recording is available publicly on the SAM website. Rhino3D is an expensive proprietary software package.
6. Autocad is an industry standard tool for architectural drafting and 3D modeling. We do not see a way to integrate Autocad functionality into SAM. The best approach

here is to better "standardize" shading input data file formats or transfer mechanisms. Autocad is an expensive proprietary software package.

7. Trimble Sketchup is a very popular 3D modeling tool formerly developed by Google. While the software was once a free tool for the public, it has been monetized and requires a purchased license for any "commercial" use. Recommendations from Nick Long and other NREL 3D modeling experts have suggested that the SAM team avoid Sketchup as a "free" or "easy integration" option due to the recent licensing restrictions. Sketchup plugins have been developed for interaction with other NREL tools in the past, notably the NREL SolTrace optical model. The author coincidentally wrote the current C++ version of SolTrace, and was involved with the Sketchup plugin development process that was done by a contractor. The adoption of the Sketchup plugin was minimal by SolTrace users for a variety of reasons. A major reason was that it was unintuitive and cumbersome to manage two desktop applications and multiple files associated with a project. Consequently, the we are hesitant to pursue the Sketchup "route", although it is a occasional suggestion we receive.
8. PVsyst is a commercial PV modeling software developed by the PVsyst SA company in Switzerland by Andre Mermoud. It incorporates a 3D modeling component for shade calculations. It is widely believed that one of the reasons for PVsyst's high adoption in the marketplace is due to its direct incorporation within the software tool of a basic 3D capability, despite reportedly being very cumbersome to use. The SAM software already incorporates methods to read in PVsyst shading output data.
9. PV*SOL Expert is a PV modeling package developed by Valentin Software in Germany. Like PVsyst, it incorporates a complex 3D modeling and shade analysis tool directly in the software. The SAM team does not have much experience with PV*SOL, but we may contact Valentin Software to see if there is a "standard" shading data output format that is utilized.
10. Helioscope is an online cloud-based PV modeling tool under development by Folsom Labs. It incorporates a 3D shade calculation engine, and we have had several conversations with the development team about improving interaction between their tool and SAM. The general outcome is that for shading, the best option would be for Helioscope to export its shading factor data that SAM could read.

Recommended Path Forward

Based on this analysis of current tools and conversations with 3D modeling experts, we propose that the best approach for DOE and SAM is to develop from scratch a basic 3D scene visualization and shade analysis software that is a part of the SAM desktop application. We list below requirements and limitations on our proposed DOE-funded capability.

The SAM shading tool will:

- Enable experienced PV modelers, researchers and students to perform basic analysis of shading impacts on PV power production for a particular scene
- Calculate hourly beam shading factors based on sun position and 3D geometry solely as fraction of total “active” area shaded
- Include a method to draw a basic 3D scene with preprogrammed crude “cartoon” models for trees, boxes, poles, and roofs
- Be able to read and write common file formats for data that can describe 3D scenes
- Enable shading analysis for rooftop solar water heating systems as a side benefit
- Only be available in the desktop SAM software for Windows and Mac OS X
- Enable the SAM team to do additional research into shading calculations

The SAM shading tool will not:

- Render specific modules, racking systems, wiring conduits, or any details of the balance of system
- Be able to display a realistic rendering or visualization of a particular PV installation with attractive lighting, coloring, texture mapping, and similar
- Have a method to create user-defined shapes and objects in the scene beyond the preprogrammed ones described above
- Be available in the SAM SDK or as an online tool

The SAM shading tool may in the future:

- Calculate non-linear shading impacts due to partial shading on a module
- Estimate diffuse view factor reductions due to blocking of the sky by geometric features
- Be scriptable using the SAM User Language (SamUL) to allow for programmatic generation of the scene geometry

- Calculate shading for 1 axis or 2 axis tracked systems, e.g. self-shading on a concentrating-PV (CPV) system on 2 axis trackers
- Provide a way for users to import an image or drawing onto the horizontal plane to assist in creating the 3D scene with relative proportionality

This set of requirements and restrictions limits the scope of the SAM shading analysis tool while also meeting the objectives outlined by DOE and the SAM TRC.

Current Status

To understand the level of complexity in developing an in-house shading, we invested a small amount of time to develop a software 3D renderer based on algorithms in [2]. We utilized an open source LGPL licensed software library to perform polygon clipping, and were able to calculate a beam shading fraction as a function of sun position for a simple fixed PV array shaded by a number of trees, as shown in Figure 1.

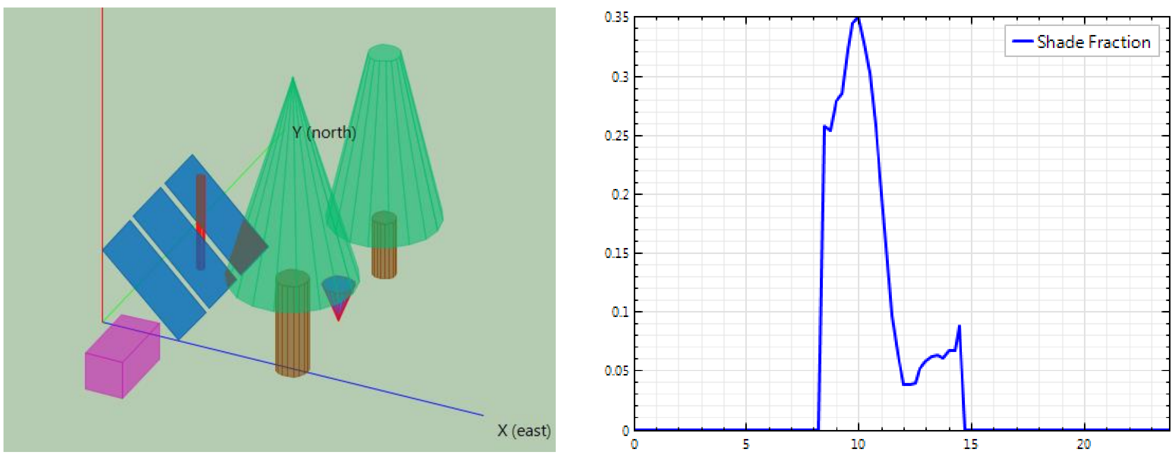

Figure 1. Representation of trees and PV array by in-house 3D shade tool

By transforming the objects shown to different angles as a function of the position of the sun in the sky, we are able to calculate the fraction of the PV array area that is obstructed. Running this calculation at many times of the day yields the shade fraction as a function of time on January 1st. This demonstration shows a viable proof-of-concept that is in line with the requirements and restrictions suggested in the previous section.

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Benefits of Proposed Approach

The key benefits to the greater solar industry resulting from adopting this roadmap include:

- A method to inexpensively estimate shading impacts on PV production based on a 3D representation of a scene
- Advocates “standardization” of shading data file formats to enable communication between different tools that people may be using
- There is a large audience (academia, small PV startups) from whom commercial tools such as Autocad or Rhino3D are completely inaccessible, and this tool would lower that barrier
- Direct integration with SAM will improve usability significantly
- Fills a major gap identified by the SAM TRC and DOE in 2013

References

1 Blair, N.; Dobos, S.; Janzou, S.; Gilman, P.; Freeman, J.; Kaffine, L. (2013). SAM Technical Review Committee Final Report: Summary and Key Recommendations from the Onsite TRC Meeting Held April 22-23, 2013. 25 pp.; NREL Report No. TP-6A20-58785.

2 Harrington, S. (1983). Computer Graphics: A Programming Approach. McGraw-Hill.